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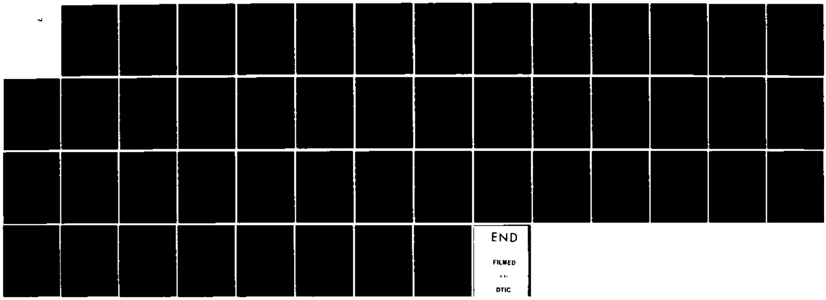

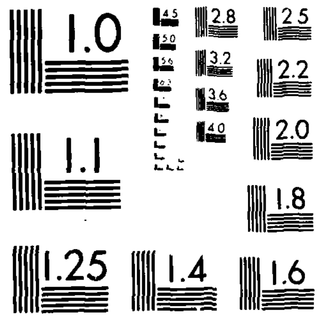

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AIR DEFENSE ENGAGEMENT SEQUENCE EVALUATION

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9 July 1984

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An air defense fire unit's engagement sequence is presented in the context of the three Joint Forward Area Air Defense issues. The engagement sequence interactions and decision processes are enumerated and problem areas identified. The engagement sequence is developed as a finite state machine to facilitate development of a closed form computer model representation.

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The views expressed in this paper are those of the author and do not necessarily reflect the position of the Joint Forward Area Air Defense Test Force.

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ABSTRACT

The Joint Forward Area Air Defense (JFAAD) Test Program Definition provides the framework for an analysis of the three JFAAD issues. The JFAAD Modeling Requirements Paper outlines general requirements for a computer model or set of models that will provide results supporting the development and refinement of solutions to the JFAAD problem. The purpose of this paper is to provide further information to link the two documents mentioned above. It will attempt to surface questions related to the analysis effort and point to an approach to answer the questions. This paper is intended to broaden the analytical framework of the two referenced documents, which will provide Government agencies with a better understanding of the JFAAD approach to the analysis and provide supporting contractors additional guidance to assist them in analytical efforts undertaken to meet JFAAD taskings.

1. PURPOSE

This paper draws on the background of both the Test Program Definition and the Model Requirements Paper and provides a more detailed discussion of the air defense functions to be represented in a computer model supporting JFAAD. The functions discussed will center around the actions at the individual air defense fire unit. The fire unit will be discussed in terms that are independent of any specific JFAAD issue by considering those functions common to all issues. The supporting measures of performance (MOP) framework for each issue will then be added to provide insight to the impact each issue has on the fire unit's actions. An approach to combining the issues will be presented to highlight some of the concerns generated by the interdependence of the issues. Although no specific results are presented, the approach may assist in the development of fire unit algorithms for use in a computer model implementation.

2. BACKGROUND

a. The JFAAD Test Program Definition[1] presents a pattern of analysis and an analysis plan for each of the three JFAAD test issues. The issues, which are explained within the Test Program Definition, are stated below:

(1) How can the collective means of aircraft identification be utilized in support of forward area air defense?

(2) How do projected command, control, communication and intelligence (C^3I) architectures and capabilities influence forward area air defense effectiveness?

(3) How do airspace management procedures affect the mission accomplishment of forward area air defense systems and friendly aircraft?

Each issue's pattern of analysis, as presented in the Test Program Definition, outlines the connectivity between the issue at the highest level and the data requirements which support the issue at the lowest level. The first level subordinate to the issue is the system, which provides the framework for the analysis of the issue. For example, the identification issue is divided into two systems: a direct identification system and an indirect identification system. JFAAD will investigate each system to determine the best way to resolve the identification issue. Each system is analyzed in terms of the measures of effectiveness (MOE), which represent the highest level measure by which each issue system will be evaluated. Subordinate to the MOE are multiple layers of MOP representing different ways the MOE can be studied to determine the significance of specific variables impacting on the issue evaluation. Finally, the specific data requirements are presented which provide the raw information feeding the MOP and serve as the fundamental elements of the analysis.

b. The JFAAD Modeling Requirements Paper[2] discusses the influence each of the issues have, both independently and interdependently, on the processes to be represented in a closed form computer model. The basic framework of the discussion is a command and control functional model adapted for specific forward area air defense concerns. Each area of modeling requirements described, from a general discussion of command and control modeling to a

detailed description of air defense engagement sequence functions, is presented without any suggestion of the level of resolution appropriate to support JFAAD. The paper draws upon the Test Program Definition's pattern of analysis by discussing some of the air defense engagement sequence functions to be modeled and listing types of data elements to be included in the functional representations. The data elements serve both as input (control variables) and output (measurement values) relating directly to the detailed data requirements within each JFAAD issue.

3. ENGAGEMENT SEQUENCE

The data requirements outlined for each issue include many detailed elements related to the fire unit's engagement sequence. The engagement sequence is critical to each issue in that the MOE--percentage of friendly aircraft killed and percentage of hostile aircraft killed--are directly impacted by the fire unit's performance and other external factors (i.e., probability of hit, probability of kill, electronic warfare, weapons system limitations). The engagement sequence is further influenced by the multiple MOP within each issue and complicates the JFAAD analysis. The Test Program Definition divides the engagement sequence into eight data requirement categories:

- enter detection zone
- detection
- enter engagement zone
- identification
- engagement
- kill
- exit engagement zone
- exit detection zone

Entering and exiting the detection and engagement zones are steps of the analysis process that are not readily discernible by most fire units, but are necessary to control fire unit evaluations. The engagement sequence steps of major concern to the fire unit are detection, identification, engagement, and kill. The tracking function, or target acquisition if using maneuver terminology, is not analyzed explicitly but incorporated into the engagement function as will be discussed later.

4. FINITE STATE MACHINE

a. This paper utilizes an analytical construct called a finite state machine, which is used in many computer science applications. The selection of this approach was based on research in two documents published by The BDM Corporation: one dealing with Automated Decision making in unit centered models[3] and the other dealing with command control in unit centered

simulations[4]. A finite state machine consists of a set of states, rules for transition between the states under various input conditions, and output definition for each state or transition. A finite state machine must be thoroughly defined so that a transition between states, following clearly defined rules, is automatic. JFAAD analyses using computer models may rely heavily on closed form, noninteractive processes. As a result, any model or models used by JFAAD must include clearly defined rules to control all the processes impacting on any of the three issues. The finite state machine meets this need and provides a useful tool for describing related JFAAD processes. When an input is made to the finite state machine, it changes state in accordance with a table that describes the machine. Computer models that attempt to replicate some decision process will often use decision logic tables in much the same way as a finite state machine to decide the next action to take.

b. The air defense fire unit's engagement sequence is represented by a finite state machine with three states.

° The first state, SEARCH, is an initial condition that may be influenced by several variables. The SEARCH state encompasses those actions performed by the fire unit while scanning for aircraft. After each scan, or SEARCH, the fire unit will enter a new state dependent on the value of the transition condition, DETECTION.

- ° DETECTION can assume two values:
  - °° NOT DETECTED, in which case the fire unit remains in the SEARCH state; or
  - °° DETECTED, in which case the fire unit transitions to the ENGAGEMENT DECISION state.
- ° The ENGAGEMENT DECISION is the process by which a commitment is made to attack or not to attack an aircraft.

c. The ENGAGEMENT DECISION state is the heart of the JFAAD analysis and includes the evaluation of all factors the fire unit takes into consideration: weapon control status, airspace management information, early warning, attack profile, etc. These influences represent different MOP to be evaluated within each issue. The impact of each MOP will be discussed as it is introduced later in the paper.

d. These factors are weighed by the fire unit to influence the transition condition, IDENTIFICATION, which can assume three values:

- ° FRIEND, in which case the fire unit can "ignore" this aircraft and return to the SEARCH state;
- ° UNKNOWN, in which case the fire unit remains in the ENGAGEMENT DECISION state; or
- ° HOSTILE, in which case the fire unit transitions to the ENGAGEMENT state.

For the JFAAD analytical evaluation using current Air Defense doctrine, the fire unit's perception of aircraft identification is of primary importance. Therefore the value of the IDENTIFICATION transition is based on the fire unit's perception concerning the aircraft's identity and not necessarily the true aircraft identity. The ENGAGEMENT DECISION state represents the time delay associated with making the decision, whereas the results of the decision are reflected in the transition to other states.

e. Although the fire unit "ignores" friendly aircraft and returns to the SEARCH state, the friendly aircraft are monitored as long as they remain in the fire unit's detection zone. This requirement will be discussed in more detail when the Single or Multiple pass aircraft MOP is presented within the framework of the Identification Issue (paragraph 6). Remaining in the ENGAGEMENT DECISION state when the aircraft is UNKNOWN reflects the fire unit's desire to continually evaluate the aircraft until a positive identification perception, either FRIEND by identification friend or foe (IFF) or HOSTILE by visual recognition or aircraft action, can be established. (The impact of weapon control statuses on this process will be presented later in paragraphs 7c(1)-(8).)

f. A HOSTILE identification value transitions the fire unit into the ENGAGEMENT state. As explained in the Test Program Definition, ENGAGEMENT is the process by which a fire unit acquires and tracks a HOSTILE aircraft and launches a round at the target. The ENGAGEMENT state accounts for the delays in tracking the aircraft and the delays while evaluating the results of an engagement. Acquisition, or tracking, is not included as a separate state because the JFAAD purpose is not to evaluate weapon system capabilities or performance. As a result, the Test Program Definition and the finite state machine concentrate on the three states already discussed (although the addition of an ACQUISITION state might make the representation more generic for all combat systems). The transition from the ENGAGEMENT state is KILL, which can assume two values:

- NOT KILLED, in which case the fire unit remains in the ENGAGEMENT state; or

- KILLED, in which case the fire unit returns to the SEARCH state.

In this context, NOT KILLED represents a miss of the target and the fire unit remains in the ENGAGEMENT state to attempt another engagement of the same target aircraft.

g. The discussion of the transition conditions has focused on the state at which each transition is introduced and the way a transition causes the change of states. The transitions are not entirely independent, and it is the combination of transition condition values that determines a state change. For example, the DETECTION transition will cause an immediate return to the SEARCH state if, for any period of time, the value of the transition becomes NOT DETECTED (i.e., the aircraft becomes masked and line of sight between the fire unit and the aircraft is interrupted). From the ENGAGEMENT DECISION state, the transition to the ENGAGEMENT state will occur only if the IDENTIFICATION transition has a HOSTILE value <u>and</u> the DETECTION transition maintains a DETECTED value.

h. An air defense fire unit continually reassesses its identification decision as it assesses its engagement results. Even after firing a round, the fire unit may determine that the aircraft is actually friendly, or at least be so uncertain as to declare the aircraft unknown. Thus the fire unit will go from the ENGAGEMENT state to the SEARCH state if the KILL transition assumes a KILLED value or the IDENTIFICATION transition assumes a FRIEND value (or the DETECTION transition assumes a NOT DETECTED value).

i. The engagement sequence finite state machine is depicted in Figure 1. The blocks represent the states, and the directed arrows represent the transition conditions. Transition conditions are combined by two operators: "•" representing "Logical AND," and "+" representing "Logical OR."

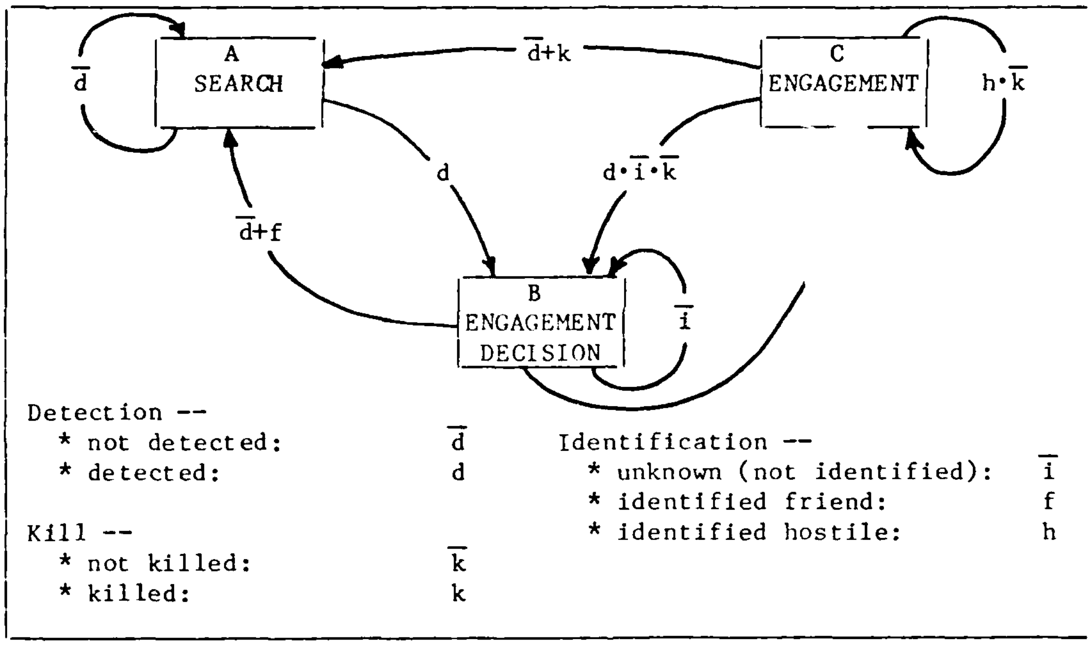


Figure 1. Engagement Sequence Finite State Machine

5. STATE TRANSITION TABLE

A finite state machine can also be represented by a State Transition Table, which reflects how the combinations of transition conditions cause the machine to change states or remain in the same state. To determine the possible combinations of transition conditions, the product of all transition values must be developed. The DETECTION transition has two values, the IDENTIFICATION transition has three values, and the KILL transition has two values for a total of twelve possible combinations (2X3X2 = 12). The engagement sequence State Transition Table appears at Table 1 with the 12 transition combinations as column headings and the three states (A-SEARCH, B-ENGAGEMENT DECISION, C-ENGAGEMENT) as row headings. The table entries show

the output state from the input state represented by the selected row given the specified combination of transition condition values. The table employs the logical operators defined above in that the logical AND operator combines the values in each column heading and the logical OR operator separates the column headings from each other. When in certain states, combinations do exist that are logically exclusive. The logically exclusive combinations are called "don't care" conditions and are represented in Table 1 by the dash "--." The State Transition Table provides a way to monitor the engagement sequence and, in effect, serves as a decision table for a computer model implementation.

TABLE 1. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE

INPUT STATE	$\overline{d}\,\overline{i}\,\overline{k}$	$\overline{d}\,\overline{i}k$	$\overline{d}f\overline{k}$	$\overline{d}fk$	$\overline{d}h\overline{k}$	$\overline{d}hk$	$d\overline{i}\,\overline{k}$	$d\overline{i}k$	$df\overline{k}$	dfk	$dh\overline{k}$	dhk
A	A	A	A	A	A	A	B	--	--	--	--	--
B	A	A	A	A	A	A	B	--	A	--	C	--
C	A	A	A	A	A	A	B	--	A	--	C	A

a. From the ENGAGEMENT state in Table 1, two combinations are "don't care" conditions: DETECTED-NOT IDENTIFIED-KILLED and DETECTED-FRIEND-KILLED. These are "don't care" conditions from the earlier explanation that only perceived HOSTILE aircraft will be engaged. If the fire unit complies with that requirement, no UNKNOWNS or FRIENDS can possibly be killed. Making combinations "don't care" does not eliminate the "percentage friendly aircraft killed" MOE because the DETECTED-HOSTILE-KILLED combination relates to <u>perceived</u> HOSTILE aircraft, and unfortunately some perceived HOSTILE aircraft may be true FRIENDS.

b. As stated earlier, the DETECTION transition will cause an immediate return to the SEARCH state if, for any period of time, the value of the transition becomes NOT DETECTED. This means that a NOT DETECTED value will take precedence over the other transition conditions as reflected in Table 1 where the output state from all input states is SEARCH (state A) in the first six columns. Combinational logic techniques can be used to demonstrate that, for all states, the first six columns of Table 1 can be condensed to a single column with the heading NOT DETECTED. The reduced State Transition Table is given at Table 2.

TABLE 2. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE

INPUT STATE	$\bar{d}$	$d\overline{ik}$	$d\bar{i}k$	$df\bar{k}$	dfk	$dh\bar{k}$	dhk
A	A	B	---	---	---	---	---
B	A	B	---	A	---	C	---
C	A	B	---	A	---	C	A

6. <u>IDENTIFICATION ISSUE</u>

The ENGAGEMENT sequence finite state machine provides a method of evaluating fire unit actions within the framework of each of the three joint test issues. To expand the finite state machine beyond the ENGAGEMENT sequence, one must place the engagement process in the context of each issue. Within the Identification issue, the ENGAGEMENT sequence is analyzed as a function of the range at which each step of the sequence occurs (i.e., DETECTION, IDENTIFICATION, ENGAGEMENT, KILL). The range from the fire unit to an aircraft impacts on the fire unit's action only to the extent that the fire unit perceives if the aircraft is still in range (or projected to remain in range) at each step of the engagement sequence, but range does not change the fire unit's sequence of action. As a result, range does not change the finite state machine representation. A not-in-range transition condition could be "OR-ed" with each condition cycling into the SEARCH state, and an in-range condition could be "AND-ed" with all other conditions. Since the addition of range only adds a variable without changing any outputs, it will not be included.

a. The analysis of range in the Identification issue is performed separately for aircraft making single and multiple passes through the fire unit's engagement zone to measure the fire unit's capability to maintain an identity on an aircraft operating within the engagement zone as the aircraft repeatedly becomes masked and unmasked. As the aircraft becomes masked, the DETECTION transition assumes a value of NOT DETECTED and the fire unit immediately returns to the SEARCH state. The possibility that an aircraft, which unmasks, may have been detected previously by the fire unit is of interest to JFAAD.

b. The requirement to analyze the fire unit's capability to maintain contact with an aircraft while it is masking and unmasking within the engagement zone introduces an additional value to the DETECTION transition: PREVIOUSLY DETECTED, which means the fire unit perceives that a detected aircraft is the same aircraft detected earlier but subsequently masked. The impact of a new DETECTION value may be reflected in a shorter period of time spent in the SEARCH state because a fire unit may focus its search on the area where the aircraft is anticipated to reappear. A PREVIOUSLY DETECTED aircraft

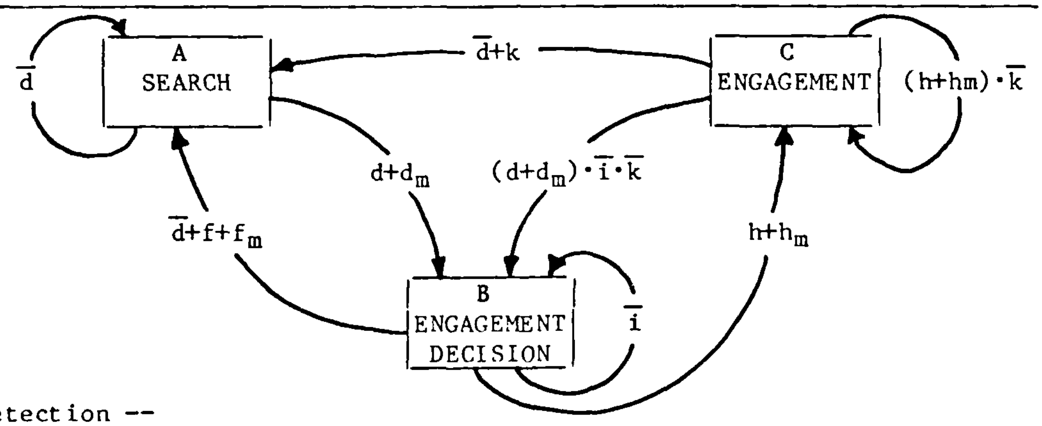
may also influence the fire unit's identification of the aircraft. The IDENTIFICATION transition may take on two new values:

° PREVIOUSLY IDENTIFIED FRIEND, or

° PREVIOUSLY IDEN -FIED HOSTILE.

The impact of the new IDENTIFICATION values may be reflected in a shorter period of time spent in the ENGAGEMENT DECISION state because, if the aircraft's perceived identity was established during an earlier unmask period (i.e., on an earlier pass) and the fire unit perceives that the aircraft is the same one when it is redetected, the fire unit may not perform all identification functions in reestablishing the aircraft's identity. Similarly, if the aircraft was PREVIOUSLY DETECTED but not identified when it masked, the fire unit may not perform all identification functions, but only those not completed prior to losing detection of the aircraft.

c. The ENGAGEMENT sequence for single or multiple pass aircraft is given at Figure 2. As can be seen, there is no difference in the number of state-to-state transitions from those shown in Figure 1. The difference is that the number of transition value combinations has increased to represent the possible change in time spent in each state. To determine the possible



Detection --
* not detected: $\bar{d}$
* detected (1st time): d
* detected on previous pass: d_m

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* identified friend: f
* friend on previous pass: f_m
* identified hostile: h
* hostile on previous pass: h_m

Figure 2. Engagement Sequence Finite State Machine Single or Multiple Pass Aircraft

combinations of transition conditions, the product of all transition values is again developed. The DETECTION transition now has three values, the IDENTIFICATION transition has five values, and the KILL transition has two values for a total of 30 possible combinations (3X5X2 = 30). However, as before, the overriding NOT DETECTED condition value can be consolidated through combinational logic to reduce the number of combinations to 21 (1+2X5X2 = 21). The combinations are detailed in Table 3, which shows the state transition table corresponding to the finite state machine of Figure 2.

TABLE 3. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
SINGLE OR MULTIPLE PASS AIRCRAFT

INPUT STATE	$\bar{d}$	$d\bar{i}\bar{k}$	$d\bar{i}k$	$df\bar{k}$	dfk	$dh\bar{k}$	dhk	$df_m\bar{k}$	df_mk	$dh_m\bar{k}$	dh_mk
A	A	B	---	---	---	---	---	---	---	---	---
B	A	B	---	A	---	C	---	---	---	---	---
C	A	B	---	A	---	C	A	---	---	---	---
INPUT STATE		$d_m\bar{i}\bar{k}$	$d_m\bar{i}k$	$d_mf\bar{k}$	d_mfk	$d_mh\bar{k}$	d_mhk	$d_mf_m\bar{k}$	d_mf_mk	$d_mh_m\bar{k}$	d_mh_mk
A		B	---	---	---	---	---	---	---	---	---
B		B	---	A	---	C	---	A	---	C	---
C		B	---	A	---	C	A	A	---	C	A

d. An examination of Table 3 reveals that a pattern of output states emerges as the number of transition condition value combinations increases. As was discussed, the added transition values (PREVIOUSLY DETECTED, PREVIOUSLY IDENTIFIED FRIEND, PREVIOUSLY IDENTIFIED HOSTILE) impact on the ENGAGEMENT sequence through the time spent in the SEARCH and ENGAGEMENT DECISION states. Combinational logic techniques can reduce the state transition table by defining relationships between transition values. For example, PREVIOUSLY DETECTED-FRIEND-NOT KILLED yields corresponding output states as the combination of PREVIOUSLY DETECTED-PREVIOUSLY IDENTIFIED FRIEND-NOT KILLED. This statement can be represented as:

$$d_mf\bar{k} + d_mf_m\bar{k} = S_i$$

where S_i is the output state defined by the input state i. The expression can be reduced to

$$d_m \cdot (f + f_m) \cdot \bar{k} = S_i$$

Since f and f_m represent the set of possible friend values that impact on the engagement sequence, the expression can be further reduced to

$$d_m F\overline{k} = S_i$$

$$\text{where} \quad F = f + f_m$$

and F represents the transitions due to a perceived identification of friend without regard for the time spent in the ENGAGEMENT DECISION state. An analysis of the components of F--f amd f_m--would evaluate the time required to identify single or multiple pass aircraft as friend.

A similar reduction process can be used to combine transitions such as DETECTED-FRIEND-NOT KILLED, and PREVIOUSLY DETECTED-FRIEND-NOT KILLED which can be represented as:

$$df\overline{k} + d_m f\overline{k} = S_j$$

where S_j is the output state defined by the input state j. The expression can be reduced to

$$Df\overline{k} = S_j$$

$$\text{where } D = d + d_m$$

and D represents the transitions due to an aircraft detection without regard for the time spent in the SEARCH state. An analysis of the components of D --d and d_m --would be performed to evaluate the time required to redetect aircraft that had become masked within the engagement zone.

e. The last four columns of the top rows of Table 3 are all "don't care" because it is logically impossible to declare an aircraft PREVIOUSLY IDENTIFIED FRIEND or PREVIOUSLY IDENTIFIED HOSTILE without a perception of a PREVIOUSLY DETECTED transition value. Since these combinations are logically exclusive, output values can be inserted artificially without changing the results. To maximize the reduction of the state transition table, artificial values corresponding to the last four columns of the bottom rows of Table 3 are inserted into the last four columns of the top rows. The logic techniques used earlier are applied across all detections, friendly identifications, and hostile identifications to yield the results shown in Table 4.

TABLE 4. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
SINGLE OR MULTIPLE PASS AIRCRAFT

INPUT STATE	$\overline{d}$	$D\overline{i}\overline{k}$	$D\overline{i}k$	$DF\overline{k}$	DFk	$DH\overline{k}$	DHk
A	A	B	---	---	---	---	---
B	A	B	---	A	---	C	---
C	A	B	---	A	---	C	A

$D = d + d_m \qquad F = f + f_m \qquad H = h + h_m$

f. Through the reduction of combinations Table 4 is equivalent to Table 2, which supports the earlier statement that incorporating single and multiple pass aircraft did not change the number of ways to transition between states, but only changed to represent the time spent in each state. The similarity between Tables 2 and 4 indicates that the engagement sequence actions are independent of whether the aircraft makes one or more passes through the fire unit's engagement zone. This fact allows a detailed evaluation of the time dependencies developed in Table 4 without concern that those dependencies add uncertainty by introducing additional steps in the process. Instead, the time dependencies may cause earlier or later detections and identifications, and the results obtained in such an analysis will assist JFAAD in answering the single-or-multiple pass MOP.

6.1 DIRECT IDENTIFICATION SYSTEM

a. The analysis of single and multiple pass aircraft through the fire unit's engagement zone is performed differently in each of the two identification systems. In the direct identification system, where the fire unit must positively identify the aircraft using its organic capabilities, the evaluation is conducted with respect to the level of early warning information received at the fire unit, which can be defined as either cueing, alerting or no information. This early warning MOP links the Identification Issue to the second issue, command and control, and allows an evaluation of the impact of different levels of early warning on the fire unit's capability to identify single or multiple pass aircraft. The primary goal of early warning is to provide the air defense fire unit with information to assist in aircraft detection and identification. Effective early warning should allow the fire unit to detect and identify aircraft earlier by directing the search toward a specific area and by providing tentative identification of the aircraft. Ineffective early warning, on the other hand, may be worse than none at all. Untimely or erroneous early warning may direct the fire unit's search to the wrong area to such an extent that aircraft are not detected, or the detected aircraft are wrongly identified based on a perceived correlation.

b. To evaluate the contribution of early warning to the direct system, new values of the DETECTION and IDENTIFICATION transitions are introduced while other values are modified. The value of the DETECTION transition is modified to represent detections that occur prior to the receipt of early warning information or detections for which the fire unit does not perceive any correlation with received early warning. A supplemental value, CORRELATED DETECTION, is added representing those detections which occur after early warning is received and the fire unit perceives that the detection correlates with the early warning. An analysis of the DETECTION transition values will provide a measure of the impact of early warning on the time spent in the SEARCH state. Higher percentages of CORRELATED DETECTIONS may indicate early warning systems with greater timeliness and accuracy.

c. The IDENTIFIED FRIEND and IDENTIFIED HOSTILE values of the IDENTIFICATION transition are modified to represent those identifications made prior to the receipt of early warning, or identifications for which the fire unit does not perceive any correlation with received early warning. Supplemental values, CORRELATED FRIENDLY IDENTIFICATION and CORRELATED HOSTILE IDENTIFICATION, are added representing those identifications that occur after receipt of early warning, and for which the fire unit perceives correlation

with the early warning. An analysis of the IDENTIFICATION transition values will provide a measure of the impact of early warning on the time spent in the ENGAGEMENT DECISION state. Higher percentages of correlated identifications may indicate early warning systems that are candidates for evaluation as indirect identification systems, which will be discussed later.

d. As with the transition values associated with single and multiple pass aircraft, the early warning transition values do not cause a change in the engagement sequence in Figure 2. Similarly, the additional values can be reduced using the logic techniques described in developing the State Transition Table at Table 4 by adding terms to the combination functions. The results of including new values in a reduced State Transition Table are shown in Table 5, which includes a legend to all the transition values.

e. The state-to-state flow resulting from the values of the IDENTIFICATION transition has been described. However, the decision process used to determine aircraft identification has not been discussed. The process, by which a value is assigned to the IDENTIFICATION transition, occurs in, and is the purpose for, the ENGAGEMENT DECISION state. The fire unit is required to use a particular means to directly identify the aircraft: visual means, electronic means (i.e., organic IFF challenge), or both. As described in the Test Program Definition, the requirement to use both means of identification forces the fire unit to visually identify and electronically challenge an aircraft prior to positively identifying those aircraft where the visual and electronic efforts agree. The JFAAD analysis employs a building block approach described earlier; therefore, the means of identification is evaluated within the framework of the available early warning. In this way an assessment can be made of the impact of the various levels of early warning on each means of direct identification --visual, electronic, or both.

f. The means of identification will be a controlled variable established at the initiation of a test and not subject to change at the fire unit's discretion. Since it cannot be changed during the test, it does not change the engagement sequence and does not require changes to the finite state machine. For clarity the IDENTIFICATION transition values in the finite state machine could be annotated visual, electronic, or both to indicate a particular test, but no other change is required.

TABLE 5. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE SINGLE OR MULTIPLE PASS AIRCRAFT IMPACT OF EARLY WARNING

INPUT STATE	$\bar{d}$	$D\bar{i}\bar{k}$	$D\bar{i}k$	$DF\bar{k}$	DFk	$DH\bar{k}$	DHk
A	A	B	---	---	---	---	---
B	A	B	---	A	---	C	---
C	A	B	---	A	---	C	A

$D = d + d_m + d_e$ $\quad$ $D = d + d_m + d_e$ $\quad$ $H = h + h_m + h_e$

Detection --
* not detected: $\bar{d}$
* detected (no early warning): d
* detected on previous pass: d_m
* detection correlated with early warning: d_e

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* friend (no early warning): f
* friend on previous pass: f_m
* friend (correlated with early warning): f_e
* hostile (no early warning): h
* hostile on previous pass: h_m
* hostile (correlated with early warning): h_e

g. Although the finite state machine does not change and no new transition values are introduced, a detailed analysis of the ENGAGEMENT DECISION state results must be made at this level. A premise used in defining a test using both visual and electronic means was that no identification would be made if the two methods did not agree. In other words, when the fire unit is required to use both means, neither takes precedence over the other in the event of a conflict. If only one means is required (i.e., visual) and the fire unit chooses to use the other means as well, the required means must serve as the basis of the decision. Doctrinal publications must be researched to define the particular means of identification that should take precedence under certain sets of circumstances when there are conflicts. JFAAD may also conduct tests of fire unit operators to determine if fire units comply with doctrinal guidance when two means of identification do not agree.

h. The doctrinal review and operational tests support the development of a decision table that could be used in a closed-form, fire unit computer model. The decision table could take the form shown in Table 6. Verification of the entries and completion of the table would be required for use in a model. Once developed, detailed analysis would be conducted to examine the impact of the required means of identification on the time spent in the ENGAGEMENT DECISION state, and the additional impact (if any) of a conflict between different means of identification or between the means of identification and early warning. The footnoted entries in Table 6 represent those situations that require further investigation prior to finalizing the table. Footnotes 1 and 2 could be eliminated by ignoring the early warning,

which would be doctrinally correct under direct identification. Small scale tests or surveys, however, might quantify the extent to which operators use the early warning information. Similarly, footnote 5 could be eliminated by ignoring the early warning, but highlighting these cases allows an in-depth examination of the impact of early warning on the direct identification system. The time sensitivities developed through such an analysis would provide integral components of the algorithm incorporated in a computer representation of the engagement sequence.

TABLE 6. DIRECT IDENTIFICATION SYSTEM IDENTIFICATION DECISION TABLE

INPUT			FIRE UNIT DECISION		
EARLY WARNING	VISUAL	ELECTRONIC	VISUAL MEANS	ELECTRONIC MEANS	BOTH
None/U	U	U	U	U	U
None/U	U	F	U	F	*3
None/U	U	H	U	H	*3
None/U	F	U	F	U	*3
None/U	F	F	F	F	F
None/U	F	H	F	H	*4
None/U	H	U	H	U	*3
None/U	H	F	H	F	*4
None/U	H	H	H	H	H
F	U	U	*1	*1	U
F	U	F	*1	F	*3
F	U	H	*1	*2	*3
F	F	U	F	*1	*3
F	F	F	F	F	F
F	F	H	F	*2	*4
F	H	U	*2	*1	*3
F	H	F	*2	F	*4
F	H	H	*2	*2	*5
H	U	U	*1	*1	U
H	U	F	*1	*2	*3
H	U	H	*1	H	*3
H	F	U	*2	*1	*3
H	F	F	*2	*2	*5
H	F	H	*2	H	*4
H	H	U	H	*1	*3
H	H	F	H	*2	*4
H	H	H	H	H	H

U: Unknown
F: Friend
H: Hostile

*1: positive early warning with unknown direct
*2: conflict between early warning and direct
*3: one unknown, one positive under both
*4: conflicting positive under both
*5: both agree but conflict with early warning

i. The next MOP level within the direct identification system delineates the type of air defense fire unit. The type fire unit MOP allows an evaluation of how well the various weapon systems apply the means of direct identification and correlate early warning information. This MOP was necessitated due to the differences in weapon system capabilities. Evaluating each weapon system independently ensures that the effectiveness of direct identification is not overstated or understated due to one dramatically superior or inferior weapon system. As with the means of direct identification, the fire unit type specifies a control implemented for the conduct of an evaluation and does not generate the need to change the representation of Figure 2.

j. The effectiveness of each weapon system will be directly related to the fire unit's capabilities, and one major factor influencing the weapon system is the category of target aircraft (i.e., fixed wing or rotary wing). Since the aircraft category may have a significant impact on the fire unit, it is included as a separate MOP. The aircraft category MOP allows an evaluation of how effectively each weapon system type utilizes the means of direct identification and responds to levels of early warning information when facing fixed and rotary wing aircraft. Once again, the aircraft category is a controlled variable set for the conduct of an evaluation and does not generate the need to change the finite state machine representation of Figure 2.

k. The MOP discussed within the framework of the direct identification system leads to the highest level question to be answered: the MOE. The effectiveness of each weapon system against both hostile and friendly fixed and rotary wing aircraft will be examined in detail to determine the effectiveness of the direct identification system. The basic structure for this analysis is the finite state machine represented in Figure 2, the state transition table in Table 5, and the decision logic diagram in Table 6.

6.2 INDIRECT IDENTIFICATION SYSTEM

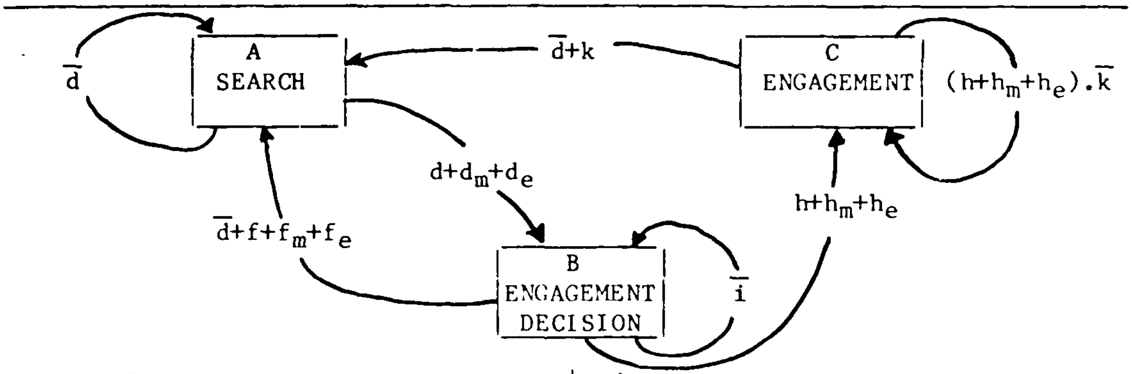
a. The Identification issue also includes the indirect system, which allows the fire unit to accept externally generated identification information and base the engagement decision upon this information without verifying the identification by organic (direct) means. Clearly, the indirect system is beyond the accepted doctrine currently in effect for short range air defense systems, but JFAAD will analyze the indirect system to determine if new capabilities for command and control make the indirect system feasible at an acceptable level of risk. If the fire unit is no longer required to identify the aircraft, the engagement sequence that is followed may vary, and the finite state machine representation must be changed to reflect these variations.

b. At the lowest level, the engagement sequence is the same for both identification systems where a similar examination of the impact of single pass versus multiple pass aircraft is conducted. Thus, the finite state machine representation in Table 2 and and the state transition table in Table 4 apply equally to both identification systems. However, at the next level of the analysis--the impact of different degrees of early warning--changes will appear between the two systems. The degrees of early warning described earlier included cueing, alerting, and no information. JFAAD considers an additional degree in the indirect system, command directed,

which is the level of early warning that directs the fire unit to engage a specific aircraft among all the ones on which early warning is received. Within each degree of early warning JFAAD will analyze the impact of the early warning on the correctness of the engagement decision for both friendly and hostile aircraft. The goal is to determine the level to which the indirect system can be relied upon to make the correct aircraft identification at the fire unit. Unfortunately, even when the indirect system is in effect, there will be times when no information is received, and the fire unit must react and make the engagement decision independently. For those instances when no early warning information is received and the indirect system is being evaluated, the fire unit will be required to identify aircraft using visual, electronic, or both means of organic capability. As defined within the direct system, these methods will be controlled variables established prior to the initiation of a test, and the fire unit will not be able to change the control during the test. The control will not change the engagement sequence processes represented in the finite state machine. Thus, Figures 2 and Table 6 represent the engagement sequence for a fire unit in the indirect identification system for those cases where no early warning information is received at the fire unit.

c. In the indirect identification system, the most critical transition value is CORRELATED DETECTION. Once the fire unit perceives that the detected aircraft is the same one on which early warning was received, the perceived identification is automatically equivalent to the tentative identification passed in the early warning. The time spent in the ENGAGEMENT DECISION state will reflect the time required to correlate the detection with the received early warning, and the evaluation provides an in-depth study of both the capability to pass accurate early warning and the capability of the fire unit to correlate detections with early warning. The fire unit's problem will be complicated when more than one aircraft is within the detection range and/or early warning has been received on more than one aircraft and/or no identification information is included in the early warning.

d. A major difference between the identification systems is that in the indirect system the fire unit does not continually reassess the engagement decision because the decision is based on information received through the command and control network. The finite state machine must reflect the fact that the fire unit will not change its decision once it perceives correlation between the early warning and the detected aircraft. The adjusted finite state machine is shown in Figure 3, where the difference between the identification systems is indicated by the omission of the transition from the ENGAGEMENT state back to the ENGAGEMENT DECISION state.



Detection --
* not detected: $\bar{d}$
* detected (no early warning): d
* detected on previous pass: d_m
* detection correlated
* with early warning: d_e

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* friend (no early warning): f
* friend on previous pass: f_m
* friend (correlated with early warning): f_e
* hostile (no early warning): h
* hostile on previous pass: h_m
* hostile (correlated with early warning): h_e

Figure 3. Engagement Sequence Finite State Machine
Indirect Identification System

e. The indirect identification state transition table appears at Table 7 and indicates that, once the fire unit enters the ENGAGEMENT state, the engagement process continues until detection is lost or the aircraft is killed. As in the direct system, HOSTILE IDENTIFICATION is "perceived hostile" rather than actual hostile; so erroneous engagements of actual friendly aircraft may still occur. Perceived hostile identifications under the indirect system provide a measure of the early warning accuracy and its impact (i.e., the impact of indirect identification) on the JFAAD MOE.

TABLE 7. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
INDIRECT IDENTIFICATION SYSTEM

INPUT STATE	$\bar{d}$	$D\bar{i}\bar{k}$	$D\bar{i}k$	$DF\bar{k}$	DFk	$DH\bar{k}$	DHk
A	A	B	---	---	---	---	---
B	A	B	---	A	---	C	---
C	A	---	---	---	---	C	A

where: $D = d + d_m + d_e$ $F = f + f_m + f_e$ $H = h + h_m + h_e$

[see Figure 3 for legend of notation used]

f. Table 8 shows the fire unit's decision table for the indirect system. The table indicates that the fire unit relies strictly on the early warning information received if aircraft identification is included in the early warning. If no identification or unknown identification is received, the fire unit must rely on its organic visual or electronic means. When that occurs, the same doctrinal or procedural issues discussed in developing the table for direct identification apply. The target assignment instruction reflected in the command directed information category is represented in Table 8 as an extension of the HOSTILE IDENTIFICATION.

TABLE 8. INDIRECT IDENTIFICATION SYSTEM
IDENTIFICATION DECISION TABLE

INPUT			FIRE UNIT DECISION		
EARLY WARNING	VISUAL	ELECTRONIC	VISUAL MEANS	ELECTRONIC MEANS	BOTH
None/U	U	U	U	U	U
None/U	U	F	U	F	*1
None/U	U	H	U	H	*1
None/U	F	U	F	U	*1
None/U	F	F	F	F	F
None/U	F	H	F	H	*2
None/U	H	U	H	U	*1
None/U	H	F	H	F	*2
None/U	H	H	H	H	H
				INDIRECT DECISION	
F				F	
H				H	
H_C				H	

U: Unknown *1: one unknown, one positive under both
F: Friend *2: conflicting positive under both
H: Hostile
H_C: Command Directed

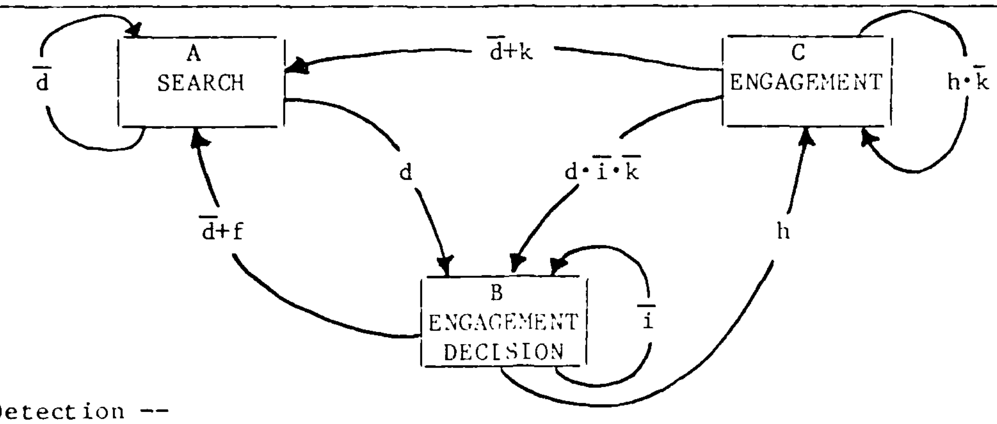
g. The next MOP level within the indirect system specifies the type of air defense fire unit. As in the direct system, the type fire unit MOP allows an evaluation of how well the various forward area weapon systems correlate the early warning information. This MOP will be used to determine which fire unit types can best utilize indirect identification and may form the basis for analysis of a third identification system, where some fire units operate under the indirect system, while others are restricted to using the direct system. The fire unit type MOP specifies a control implemented for the conduct of an evaluation and does not generate the need to change the representation of Figure 3.

h. The remaining analysis levels in the indirect system are the aircraft category MOP and the MOE. As discussed in the direct system, these levels provide controls on the evaluation without changing the engagement sequence. The structure for the indirect system analysis is the finite state machine in Figure 3, the state transition table in Table 7, and the decision logic diagram in Table 8. The similarity between the evaluation of the direct and indirect systems ensures that differences in the effectiveness of the two systems can be easily highlighted because a direct comparison can be made at almost every MOP level. This analytical approach will be utilized in each of the other issues as well.

7. COMMAND AND CONTROL ISSUE

a. The engagement sequence is also instrumental to the analysis of the command and control issue because the resolution of the issue is determined in terms of the two MOE introduced earlier: the percent of friendly aircraft killed and the percent of hostile aircraft killed. The command and control issue is evaluated by comparing three systems, which are fully described in the Test Program Definition. The three systems relate to the projected SHORAD command and control system to be fielded by 1986, the follow-on system resulting from completion of the Army's Air Defense Command and Control project, and further enhancements (to be identified) of interest to JFAAD. The analytical structure represented through several MOP levels is the same for each of the three command and control systems. However, the MOP framework is complicated because some MOP relate directly to the fire unit's engagement sequence, while others relate indirectly in measuring the capability of the supporting communication system to get information to the fire unit. For the purpose of this paper, the communication MOP are peripheral to the discussion and will not be included. Instead, only those actions taken by the fire unit once the information is available are presented. The communication MOP allow an evaluation of the timeliness, accuracy and completeness of the information to identify information bottlenecks across any communication linkage.

b. The basic engagement sequence, shown in Figure 1, is independent of any issue. To concentrate on the command and control issue and maintain independence from the identification issue, the engagement sequence will be redeveloped without using the extensions added for the two identification systems. The finite state machine shown in Figure 4 is an exact copy of Figure 1.



Detection --
* not detected: $\bar{d}$
* detected: d

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* identified friend: f
* identified hostile: h

Figure 4. Engagement Sequence Finite State Machine

c. The first MOP applied to the engagement sequence within the command and control issue examines the impact of the fire unit's weapon control status. There are currently three weapon control statuses, and JFAAD has added a fourth as an extension of present doctrine on which to base this MOP. The three doctrinal weapon control statuses are: Weapons Hold, which permits the fire unit to engage only in self defense or when the asset to which the fire unit is attached is under attack; Weapons Tight, which permits the fire unit to engage only those aircraft positively identified as HOSTILE; and Weapons Free, which permits the fire unit to engage those aircraft that are not positively identified as FRIEND. The fourth breakout added by JFAAD is Command Directed which, as described under the indirect identification system, permits the fire unit to engage by identifying a specific aircraft via the command and control system. It is added at this level in the command and control issue because whenever Command Directed information is available, it could override any other weapon control status for the specified aircraft.

(1) Adding the weapon control status to the engagement sequence finite state machine introduces a complication not encountered with any MOP discussed in the identification issue. Each weapon control status affects the ENGAGEMENT DECISION state differently, and therefore each one causes a different transition from the ENGAGEMENT DECISION state.

(2) The second weapon control status that was defined above, Weapons Tight, is the normal control measure placed on forward area air defense units. It allows the fire unit to engage those aircraft perceived as HOSTILE without requiring the fire unit to distinguish between an attacking aircraft and one transiting the detection zone. This was the weapon control status implicit in the discussion of the identification issue and, as a result, Figure 4 represents the engagement sequence for a fire unit under Weapons Tight.

(3) The most restrictive weapon control status is Weapons Hold. In the finite state machine, the requirement to determine that an aircraft is not only hostile but also attacking adds a new value to the IDENTIFICATION transition: ATTACKING HOSTILE. Aircraft perceived as HOSTILE but not attacking will be monitored without being engaged until detection is lost or the aircraft initiates an attack. The analysis of this weapon control status will be very valuable because it will indicate the capability of forward area air defense fire units to detect an attack maneuver. Modern aircraft, with sophisticated ordnance, use delivery techniques that may not be discernible to large numbers of fire units. By evaluating the perception of ATTACKING HOSTILE aircraft, JFAAD will determine if this weapon control status is still an effective means of controlling SHORAD assets. The Finite State Machine for Weapons Hold is given in Figure 5.

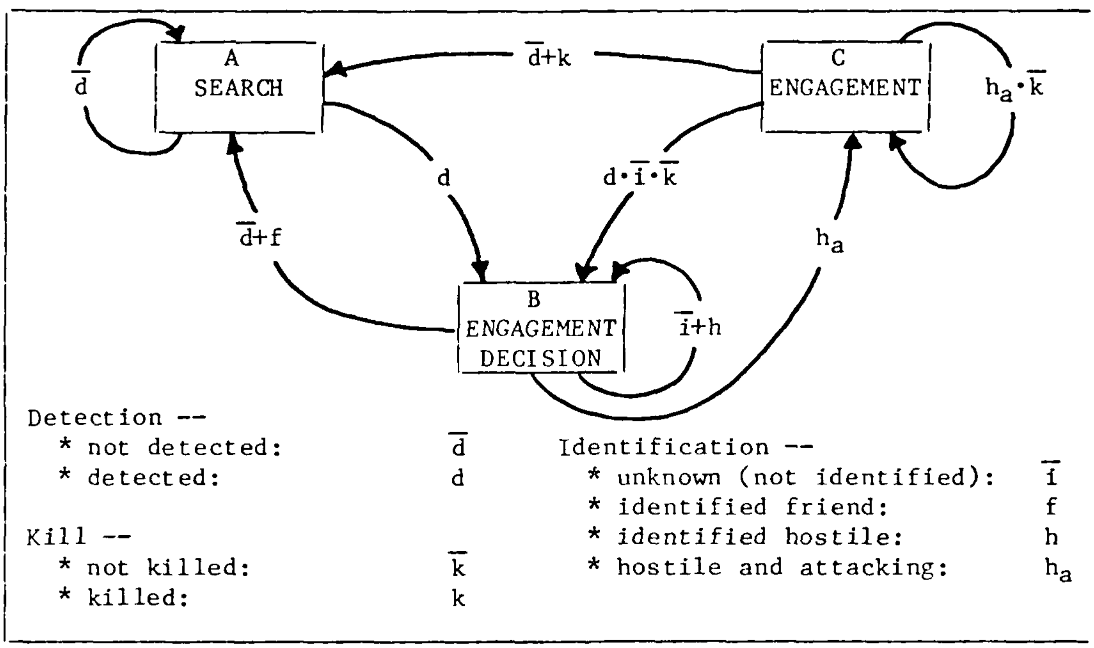
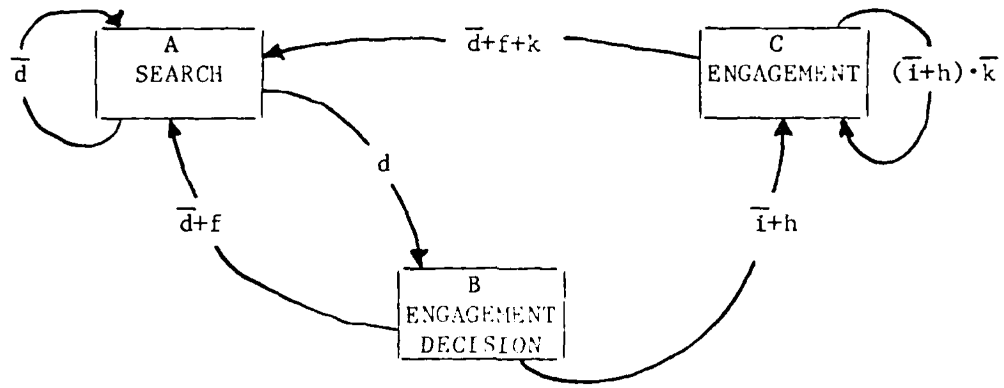


Figure 5. Engagement Sequence Finite State Machine Weapons Hold

(4) In contrast to Weapons Hold, Weapons Free is the least restrictive weapon control status. When the fire unit may engage aircraft not positively identified as FRIEND (i.e., UNKNOWN aircraft), the fire unit may spend very little time in the ENGAGEMENT DECISION state thereby erroneously engaging more actual friendly aircraft. Conversely, less time in the ENGAGEMENT DECISION state may mean that the fire unit initiates engagements earlier, increasing (or decreasing?) the likelihood of successfully completing engagements resulting in more (or fewer) HOSTILE aircraft kills. The evaluation of this MOP will allow JFAAD to analyze the impact of Weapons Free on both MOE. The finite state machine for Weapons Free is given in Figure 6.



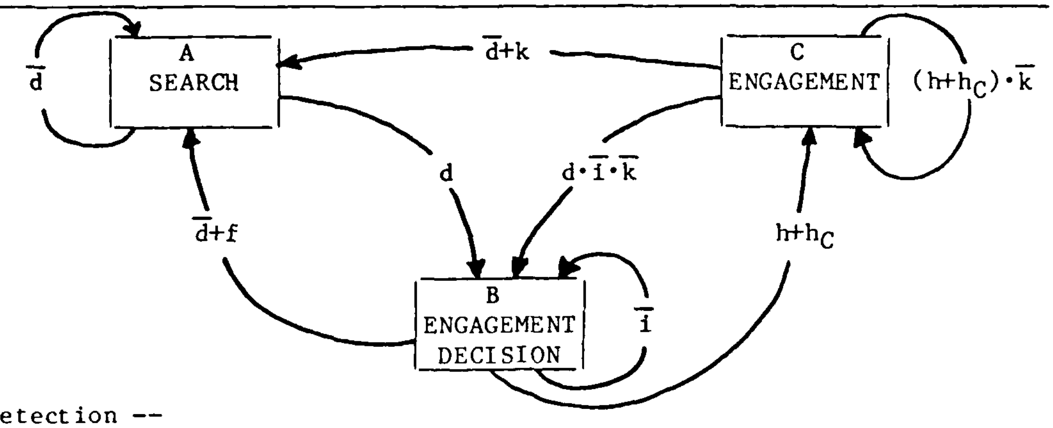
Detection --
* not detected: $\bar{d}$
* detected: d

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* identified friend: f
* identified hostile: h

Figure 6. Engagement Sequence Finite State Machine Weapons Free

e. Developing the finite state machine for Command Directed engagements is more complicated. Fire units cannot be under Command Directed control without receiving early warning, and early warning is not introduced at this MOP level. As a result, there can be no Command Directed engagements without a detection that is correlated with the received early warning. For consistency in comparing the engagement sequence at the weapon control status MOP level, the same DETECTION values used in Figures 4 through 6 will be used to represent the Command Directed process. This simplification will be removed when the early warning MOP is introduced. The Command Directed finite state machine appears at Figure 7, which builds the Command Directed decision process around Weapons Tight in Figure 4.



Detection --
* not detected: $\bar{d}$
* detected: d

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* identified friend: f
* identified hostile: h
* hostile, command directed engagement: h_C

Figure 7. Engagement Sequence Finite State Machine Weapons Tight with Command Direct

(5) The state transition tables for each weapon control status summarize the differences discussed in developing each value independently. All four state transition tables appear in Table 9, and for comparison purposes, the ATTACKING HOSTILE value developed under Weapons Hold and the COMMAND DIRECTED HOSTILE value developed under Command Directed control are included in all state transition tables. The ATTACKING HOSTILE value is shown to lead to engagements under all weapon control statuses reflecting the doctrinal statement that the right to self defense is never denied. The Command Directed transitions are subject to the same simplifying ssumption made earlier: the detections are correlated with early warning about the aircraft. As in Figure 7, Command Directed transitions overlay the Weapons Tight decision process.

(6) Table 9 shows that in the ENGAGEMENT DECISION state, DETECTED-HOSTILE-NOT KILLED keeps the fire unit in that state. However, the same combination also appears in the ENGAGEMENT state and returns the fire unit to the ENGAGEMENT state. Under Weapons Hold, the fire unit only enters the ENGAGEMENT state if the aircraft is perceived as ATTACKING HOSTILE, but once in the state the engagement process continues as long as the aircraft is detected even if the aircraft is no longer attacking. This situation corresponds to the unfortunate role in which forward area air defense units often find themselves: serving as revenge weapons, where an attacking aircraft is unsuccessfully engaged and the engagement continues in an attempt to prevent the aircraft from returning for another attack.

TABLE 9. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
WEAPON CONTROL STATUS IMPACT

WEAPONS HOLD

INPUT STATE	$\bar{d}$	$d\overline{ik}$	$d\bar{i}k$	$df\bar{k}$	dfk	$dh\bar{k}$	dhk	$dh_a\bar{k}$	dh_ak	$dh_c\bar{k}$	dh_ck
A	A	B	---	---	---	---	---	---	---	---	---
B	A	B	---	A	---	B	---	C	---	---	---
C	A	B	---	A	---	C	A	C	A	---	---

WEAPONS TIGHT

INPUT STATE	$\bar{d}$	$d\overline{ik}$	$d\bar{i}k$	$df\bar{k}$	dfk	$dh\bar{k}$	dhk	$dh_a\bar{k}$	dh_ak	$dh_c\bar{k}$	dh_ck
A	A	B	---	---	---	---	---	---	---	---	---
B	A	B	---	A	---	C	---	C	---	---	---
C	A	B	---	A	---	C	A	C	A	---	---

WEAPONS FREE

INPUT STATE	$\bar{d}$	$d\overline{ik}$	$d\bar{i}k$	$df\bar{k}$	dfk	$dh\bar{k}$	dhk	$dh_a\bar{k}$	dh_ak	$dh_c\bar{k}$	dh_ck
A	A	B	---	---	---	---	---	---	---	---	---
B	A	C	---	A	---	C	---	C	---	---	---
C	A	C	A	A	---	C	A	C	A	---	---

COMMAND DIRECT

INPUT STATE	$\bar{d}$	$d\overline{ik}$	$d\bar{i}k$	$df\bar{k}$	dfk	$dh\bar{k}$	dhk	$dh_a\bar{k}$	dh_ak	$dh_c\bar{k}$	dh_ck
A	A	B	---	---	---	---	---	---	---	---	---
B	A	B	---	A	---	C	---	C	---	C	---
C	A	B	---	A	---	C	A	C	A	C	A

(7) The weapon control status is, at least implicitly, the basis on which the fire unit makes an engagement decision. Commanders at all echelons can limit air defense fires most easily through the imposition of more restrictive weapon control statuses. The fire unit's engagement decision is based on the identification decision described earlier. The weapon control status definitions translate into the engagement decisions reflected in Table 10.

Table 10 points out two problems that must be resolved for the air defense fire unit. The first problem is reflected by the question marks under command directed engagements. The solution to this problem is suggested by the earlier discussion of command directed: when no command directed information is received, the fire unit responds in accordance with the underlying doctrinal weapon control status. The second problem is reflected by the multiple engagement possibilities under Weapons Tight and Weapons Free. High altitude air defense systems, and some new SHORAD systems, use automated target evaluation and weapon assignment procedures to accomplish threat ordering. For manual systems it is not as clear how the fire unit prioritizes engagements when multiple simultaneous opportunities are present. Doctrinal manuals must be researched to identify the correct prioritization scheme, and gunners must be interviewed to determine the level to which doctrinal techniques are applied by fire units.

TABLE 10. FIRE UNIT ENGAGEMENT DECISION

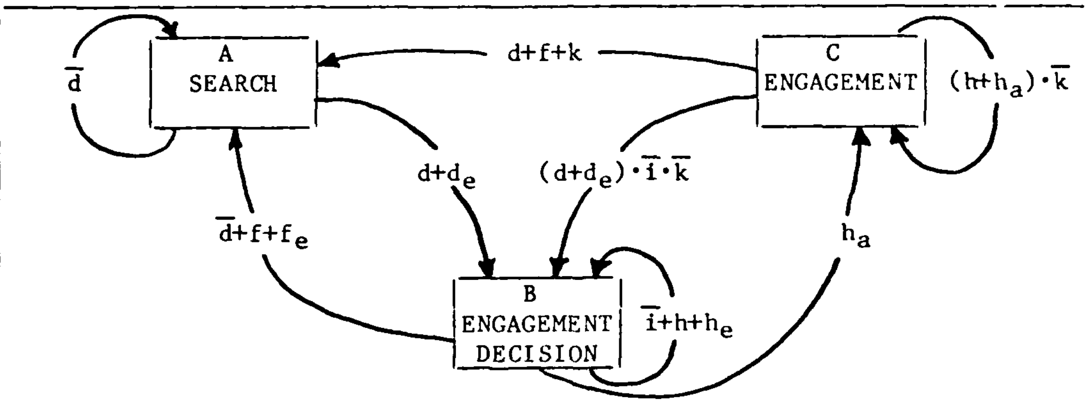
FIRE UNIT IDENTIFICATION	WEAPONS HOLD	WEAPONS TIGHT	WEAPONS FREE	COMMAND DIRECTED
U	$\overline{E}$	$\overline{E}$	E	?
F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
H	$\overline{E}$	E	E	?
H_A	E	E	E	?
H_C	---	---	---	E

$\overline{E}$: Do Not Engage E: Engage

(8) The impact of each weapon control status is analyzed with respect to the amount of early warning information received at the fire unit. This MOP identifies three levels of early warning for evaluation: cueing, alerting, and no information. The early warning MOP was also included in the identification issue and is the principle link between the two issues. The evaluation of early warning in the identification issue concentrates on determining the impact of early warning on the fire unit's identification decision. Because of the dependence of the identification decision on early warning rather than the direct dependence of the engagement decision on early warning, no attempt is made to expand Table 10 at this point to include early warning. Early warning considerations will be included later (paragraph 9) when linking all three issues. In the command and control issue, the analysis of this MOP provides a more in-depth look at the accuracy of the early warning in terms of the actual location of the aircraft relative to the location passed in the early warning. Additional timeliness and accuracy measures relate to whether information is received in time to assist the fire unit and whether the information received is correct.

d. To evaluate the contribution of early warning, the early warning transition values introduced in the identification issue are used: CORRELATED DETECTION, CORRELATED FRIENDLY IDENTIFICATION, and CORRELATED HOSTILE IDENTIFICATION. As explained before, these represent "perceived correlations" by the fire unit and not actual correlations. The analysis of the differences between perceived and actual correlations provides a measure of the timeliness, accuracy and completeness of the early warning.

(1) Other transition values (DETECTED, IDENTIFIED FRIEND, and IDENTIFIED HOSTILE) are modified as in the identification issue to represent those functions completed prior to the receipt of early warning or the functions for which the fire unit had information but did not perceive any correlation with detected aircraft. The early warning transition values are reflected in Figure 8 for the fire unit under Weapons Hold. As in the identification issue, the number of state-to-state transitions does not change when the early warning MOP is added. The difference is that the number of combinations of transition values has increased to represent the possible changes in the time spent in each state as a result of the early warning information's impact on the fire unit. Clearly, similar results could be observed in the finite state machines corresponding to the other weapon control statuses, which will not be presented here in the interest of brevity.



Detection --
* not detected: $\bar{d}$
* detected (no early warning): d
* detection correlated with early warning: d_e

Kill --
* not killed: $\bar{k}$
* killed: k

Identification --
* unknown (not identified): $\bar{i}$
* friend (no early warning): f
* friend correlated with early warning: f_e
* hostile (no early warning): h
* hostile correlated with early warning: h_e
* hostile attacking: h_a

Figure 8. Engagement Sequence Finite State Machine
Weapons Hold With Early Warning

(2) It was shown earlier that the basic form of the state transition table remained unchanged due to the introduction of combinational logic and substitute values for DETECTION, FRIENDLY IDENTIFICATION, and HOSTILE IDENTIFICATION. It is of interest to determine if the same reduction techniques can be applied in this issue and extended to include ATTACKING HOSTILE and COMMAND DIRECTED HOSTILE.

(3) The total number of transition combinations must be developed to analyze the ability to apply the reduction techniques. Within the command and control engagement sequence, the DETECTION transition has three values, the IDENTIFICATION transition has seven values, and the KILL transition has two values. One value of the DETECTION transition, NOT DETECTED, is an overriding value as indicated in Table 9. As a result there are 29 transition combinations (1+2X7X2 = 29). The combinations are detailed in Table 11, which corresponds to the Weapons Hold weapon control status with early warning for the finite state machine at Figure 8. The state transition table includes the COMMAND DIRECTED HOSTILE value (see Table 9) to allow comparison with the other weapon control statuses although this IDENTIFICATION transiti^n value is a "don't care" condition under Weapons Hold.

(4) Table 11 shows the "don't care" conditions resulting from logically exclusive combinations (i.e., DETECTED-CORRELATED FRIEND-NOT KILLED). For both CORRELATED FRIEND and CORRELATED HOSTILE, there must first be a CORRELATED DETECTION. A similar statement was made when introducing COMMAND DIRECTED HOSTILE: the detections must be correlated before the fire unit can comply with command directed control. The Command Directed process was simplified in the earlier discussion by assuming correlated detections. This simplification can be removed by overlaying Command Directed control on the Weapons Hold weapon control status as indicated in Figure 12. The differences between Tables 11 and 12 are the additional transitions to the ENGAGEMENT state when Command Directed engagement orders are correlated with detections. The DETECTION-COMMAND DIRECTED HOSTILE-NOT KILLED combination remains logically exclusive since the fire unit cannot correlate a detection with the early warning to know which hostile aircraft it is directed to engage.

TABLE 11. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
WEAPONS HOLD WITH EARLY WARNING

INPUT STATE	$\overline{d}$	$d\overline{i}\overline{k}$	$d\overline{i}k$	$df\overline{k}$	dfk	$df_e\overline{k}$	df_ek	$dh\overline{k}$	dhk	$dh_e\overline{k}$	dh_ek	$dh_a\overline{k}$	dh_ak	$dh_c\overline{k}$	dh_ck
A	A	B	---	---	---	---	---	---	---	---	---	---	---	---	---
B	A	B	---	A	---	---	---	B	---	---	---	C	---	---	---
C	A	B	---	A	---	---	---	C	A	---	---	C	A	---	---

INPUT STATE	$d_e\overline{i}\overline{k}$	$d_e\overline{i}k$	$d_ef\overline{k}$	d_efk	$d_ef_e\overline{k}$	d_ef_ek	$d_eh\overline{k}$	d_ehk	$d_eh_e\overline{k}$	d_eh_ek	$d_eh_a\overline{k}$	d_eh_ak	$d_eh_c\overline{k}$	d_eh_ck
A	B	---	---	---	---	---	---	---	---	---	---	---	---	---
B	B	---	A	---	A	---	B	---	B	---	C	---	---	---
C	B	---	A	---	A	---	C	A	C	A	C	A	---	---

(5) The pattern of output states in Table 12 is similar to the pattern observed in the identification issue state transition tables, with one exception. The exception in the Weapons Hold table (Table 12) is that the ENGAGEMENT DECISION state (State B) does not have the same output for HOSTILE aircraft as for ATTACKING HOSTILE aircraft. HOSTILE IDENTIFICATIONs follow the same pattern as CORRELATED HOSTILE IDENTIFICATIONs, and ATTACKING HOSTILE aircraft follow the same pattern as COMMAND DIRECTED HOSTILE aircraft. By artificially inserting output values from the CORRELATED DETECTION combinations into the logically exclusive Detection combinations, the pattern between DETECTIONS and CORRELATED DETECTIONS is equivalent without changing the actual output of the finite state machine. The reduction techniques are applied across the DETECTION and IDENTIFICATION values for each weapon control status using Table 9 as the basic breakout and the detailed discussion of Weapons Hold in Table 12 as extended to Weapons Tight and Weapons Free. Since the Command Directed control technique has been explained within the Weapons Hold discussion, it is incorporated into each weapon control status and not presented separately. This is consistent with the description of Command Directed, which stated that it is a control measure applied to specific aircraft while the fire unit still operates under a standard weapon control status for other engagements. The reduced state transition table for each weapon control status is provided in Table 13.

TABLE 12. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE WEAPONS HOLD WITH EARLY WARNING AND COMMAND DIRECTED CONTROL

INPUT STATE	$\bar{d}$	$d\overline{ik}$	$d\bar{i}k$	$df\bar{k}$	dfk	$df_e\bar{k}$	df_ek	$dh\bar{k}$	dhk	$dh_e\bar{k}$	dh_ek	$dh_a\bar{k}$	dh_ak	$dh_c\bar{k}$	dh_ck
A	A	B	---	---	---	---	---	---	---	---	---	---	---	---	---
B	A	B	---	A	---	---	---	B	---	---	---	C	---	---	---
C	A	B	---	A	---	---	---	C	A	---	---	C	A	---	---

INPUT STATE	$d_e\overline{ik}$	$d_e\bar{i}k$	$d_ef\bar{k}$	d_efk	$d_ef_e\bar{k}$	d_ef_ek	$d_eh\bar{k}$	d_ehk	$d_eh_e\bar{k}$	d_eh_ek	$d_eh_a\bar{k}$	d_eh_ak	$d_eh_c\bar{k}$	d_eh_ck
A	B	---	---	---	---	---	---	---	---	---	---	---	---	---
B	B	---	A	---	A	---	B	---	B	---	C	---	C	---
C	B	---	A	---	A	---	C	A	C	A	C	A	C	A

TABLE 13. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
WEAPON CONTROL STATUSES WITH EARLY WARNING

INPUT STATE	$\overline{d}$	$D\overline{ik}$	$D\overline{i}k$	$DF\overline{k}$	DFk	$DH_1\overline{k}$	DH_1k	$DH_2\overline{k}$	DH_2k
				WEAPONS HOLD					
A	A	B	---	---	---	---	---	---	---
B	A	B	---	A	---	B	---	C	---
C	A	B	---	A	---	C	A	C	A
				WEAPONS TIGHT					
INPUT STATE	$\overline{d}$	$D\overline{ik}$	$D\overline{i}k$	$DF\overline{k}$	DFk	$DH_1\overline{k}$	DH_1k	$DH_2\overline{k}$	DH_2k
A	A	B	---	---	---	---	---	---	---
B	A	B	---	A	---	C	---	C	---
C	A	B	---	A	---	C	A	C	A
				WEAPONS FREE					
INPUT STATE	$\overline{d}$	$D\overline{ik}$	$D\overline{i}k$	$DF\overline{k}$	DFk	$DH_1\overline{k}$	DH_1k	$DH_2\overline{k}$	DH_2k
A	A	B	---	---	---	---	---	---	---
B	A	C	---	A	---	C	---	C	---
C	A	C	A	A	---	C	A	C	A

where $D = d + d_e$ $F = f + f_e$ $H_1 = h + h_e$ $H_2 = h_a + h_c$

e. The next MOP level within the command and control issue examines the contribution of each air defense fire unit type. The type fire unit MOP allows an evaluation of how well the various forward area weapon systems receive and utilize the information passed over the command and control system. Evaluating each weapon system independently ensures that the effectiveness of a specific command and control system being evaluated is not overstated or understated due to one dramatically superior or inferior weapon system. As in the identification issue, the type fire unit specifies a control implemented for the conduct of an evaluation and does not generate the requirement to change the engagement sequence representation.

f. The effectiveness of each weapon system type within a particular command and control system may be influenced by the category of target aircraft (i.e., fixed wing or rotary wing). The aircraft category is the next higher level MOP to allow an analysis of the capability of the command and control system to monitor and relay information concerning both fixed wing and rotary wing aircraft. The aircraft category is a control implemented for the conduct of an evaluation, and as a result it does not generate the requirement to change the engagement sequence representation already developed.

g. The MOP presented within the command and control issue support the analysis of the JFAAD MOE. Within each of the three command and control systems, the analysis structure allows a detailed examination of the system's effectiveness against friendly or hostile aircraft, both fixed wing and rotary wing. Additionally, this effectiveness can be addressed in terms of the contribution of each fire unit and the capability of each fire unit type to correlate varying degrees of early warning while complying with different weapon control statuses. From the fire unit's perspective, all the elements of this analysis can be addressed from the engagement sequence representation depicted in the state transition table of Table 13.

8. AIRSPACE MANAGEMENT ISSUE

a. The airspace management issue is divided into three airspace management systems that utilize the same analytical structure. The first system provides an evaluation of the current European airspace management system, while the second system addresses the current Southwest Asia airspace management system. The third system will be defined by JFAAD after the analysis of the first two systems in an attempt to identify an excursion system that optimizes the performance of the current systems.

b. Airspace management is a very complex process for which there has been little service testing in recent years, although new initiatives are aimed at overcoming some of the commonly observed airspace management problems. Airspace management is an area where the JFAAD analysis will potentially provide a great impact. The issue is divided into an analysis of how the airspace management system impacts the forward area air defense weapon systems' effectiveness and how the airspace management system impacts supporting friendly aircraft effectiveness. For the purpose of this paper, only the impact of the airspace management system on the fire unit's effectiveness will be addressed.

c. The analytical structure of the airspace management issue introduces only one new MOP to the fire unit's engagement sequence. The basic airspace management measures that comprise the airspace management system are delineated so the impact of each measure on the system's performance can be measured. The minimum airspace management measures identified as components of this MOP level are: Zones, such as free fire zones, restricted fire zones; altitudes, such as sanctuary levels, coordinating altitudes; routes, such as low level transit routes, safe passage corridors; and no airspace management measures in effect. Other airspace management measures could be introduced for an analysis at this level to provide a basis of comparison between the specific measure and the instances when no airspace management measure is in effect. There are actually two divisions of the no measure in effect category. In one circumstance, there may be no airspace management measure overlapping any of the detection zone of the fire unit being evaluated. In the other circumstance there may be an airspace management measure overlapping some portion of the fire unit's detection zone, but the detected aircraft is not perceived to be operating in that portion of the detection zone. This is a subtle difference that may generate significantly different results.

d. The airspace management measure is analyzed as the lowest level MOP above the generalized engagement sequence. It is not anticipated that the airspace management measure will impact on the fire unit's capability to detect aircraft, and therefore this MOP will not affect the SEARCH state of the fire unit. The major impact will be in the ENGAGEMENT DECISION state where the fire unit will assess whether the aircraft is complying with the airspace management measure in effect and perhaps use that assessment as a factor in identifying the aircraft. Current SHORAD doctrine does not specify the conditions under which airspace management compliance or noncompliance should impact on the identification and engagement decisions. This is one of the major problems with current airspace management policies that will be addressed by JFAAD. Although the actual transitions from the ENGAGEMENT DECISION state cannot be specified, the impact can be highlighted in a fire unit decision table. As with the tables developed in the other issues, the airspace management decision table can point out those unresolved areas that require a detailed doctrinal search combined with tests of operational personnel before being incorporated into a JFAAD computer model. The table could then be used by the model to assess the impact of those decisions on the overall system effectiveness. The impact of the airspace management compliance on the fire unit's identification decision is presented at Table 14. The fire unit's perception that an aircraft is not influenced by any airspace management measure due to no measure in effect or no measure in effect in the same portion of the detection zone is indicated by "A", which is read NOT APPLICABLE. The NOT APPLICABLE condition could be divided to allow the analysis of the subtle differences described earlier. For example, A_Z could indicate that no measure is in effect anywhere in the fire unit's detection zone, and A_R could indicate that no measure is in effect in the region of the detection zone where the aircraft is operating. The two conditions will be combined here [where $A = A_Z + A_R$], but the separation may be considered in future delineations of JFAAD analytical requirements.

TABLE 14. AIRSPACE MANAGEMENT IMPACT ON IDENTIFICATION DECISION

ASM COMPLIANCE	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$
EARLY WARNING	U	U	U	U	U	U	U	U	U	F	F	F	F	F	F	F	F	F	H	H	H	H	H	H	H	H	H
VISUAL	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H
ELECTRONIC	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H
ID DECISION	U	*	*	*	*	*	*	*	*	*	*	*	*	F	*	*	*	*	*	*	*	*	*	*	*	*	H
ASM COMPLIANCE	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
EARLY WARNING	U	U	U	U	U	U	U	U	U	F	F	F	F	F	F	F	F	F	H	H	H	H	H	H	H	H	H
VISUAL	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H
ELECTRONIC	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H
ID DECISION	U	*	*	*	*	*	*	*	*	*	*	*	*	F	*	*	*	*	*	*	*	*	*	*	*	*	H
ASM COMPLIANCE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
EARLY WARNING	U	U	U	U	U	U	U	U	U	F	F	F	F	F	F	F	F	F	H	H	H	H	H	H	H	H	H
VISUAL	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H
ELECTRONIC	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H
ID DECISION	?	*	*	*	*	*	*	*	*	*	*	*	*	F	*	*	*	*	*	*	*	*	*	*	*	*	?
ASM COMPLIANCE	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
EARLY WARNING	U	U	U	U	U	U	U	U	U	F	F	F	F	F	F	F	F	F	H	H	H	H	H	H	H	H	H
VISUAL	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H	U	U	U	F	F	F	H	H	H
ELECTRONIC	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H	U	F	H
ID DECISION	?	*	*	*	*	*	*	*	*	*	*	*	*	?	*	*	*	*	*	*	*	*	*	*	*	*	H

e. When the fire unit perceives that an airspace management measure is in effect, there are still three perceptions that can be made concerning the aircraft's compliance: U, or Unknown; Y, or yes for Compliance; and N, or no for Noncompliance. The asterisks in the Fire Unit Decision row of Table 14 indicate situations that may be largely resolved through analysis of Table 5 and Table 8 in the identification issue. The question marks are the most obvious areas where the airspace management perception may generate an inconsistency in the identification results. All of these entries must be completely resolved to assure doctrinal validity, or at least acceptability, prior to incorporating the airspace management decision process into a JFAAD computer model. Until the entries are clearly defined, the state-to-state transitions in the engagement sequence cannot be completed.

f. The additional MOP in this issue involve the evaluation of the effectiveness of each type fire unit, the impact of the airspace management measures on the fire unit's interactions with each category of aircraft, and finally the ultimate analysis of the MOE. As discussed in both previous issues, the type fire unit and aircraft category impose controls on specific evaluations and do not change the fire unit engagement sequence. As a result, no additional discussion of the engagement sequence is required to complete the analysis of the impact of airspace management on the forward area air defense weapon systems.

9. COMBINING THE ISSUES

Each of the three issues has been addressed separately to the extent possible. Within each discussion the impact of the issue on the engagement sequence was developed. The interrelationship of the issues through the identification decision suggests that the individual representations of the engagement sequence can be combined to provide a perspective on the required analysis.

a. Combining the first two issues is based on the highest level state transition tables developed in those issues, Table 6 (direct identification system) and Figure 13 (weapon control statuses with Command Directed control). The entries in Table 6 correspond to the Weapons Tight entries in Figure 13, although there are additional variables accounted for in the identification issue. The additional terms relate to multiple pass aircraft, which was not included in the command and control issue. The similarity between the two figures suggests that adding the multiple pass transition values to the command and control issue does not change the resulting engagement sequence. Combinational logic techniques can be used to prove the validity of this assumption, and the results of combining direct identification with the command and control issue are shown in Table 15. The indirect identification system (Table 7) reflects the differences between the two identification systems in the transitions from the ENGAGEMENT state (State C). Therefore it is a simple matter to combine the command and control representation with the indirect system yielding Table 16.

TABLE 15. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
COMMAND AND CONTROL WITH DIRECT IDENTIFICATION

WEAPONS HOLD

INPUT STATE	$\bar{d}$	$D\overline{ik}$	$D\bar{i}k$	$DF\bar{k}$	DFk	$DH_1\bar{k}$	DH_1k	$DH_2\bar{k}$	DH_2k
A	A	B	---	---	---	---	---	---	---
B	A	B	---	A	---	B	---	C	---
C	A	B	---	A	---	C	A	C	A

WEAPONS TIGHT

INPUT STATE	$\bar{d}$	$D\overline{ik}$	$D\bar{i}k$	$DF\bar{k}$	DFk	$DH_1\bar{k}$	DH_1k	$DH_2\bar{k}$	DH_2k
A	A	B	---	---	---	---	---	---	---
B	A	B	---	A	---	C	---	C	---
C	A	B	---	A	---	C	A	C	A

WEAPONS FREE

INPUT STATE	$\bar{d}$	$D\overline{ik}$	$D\bar{i}k$	$DF\bar{k}$	DFk	$DH_1\bar{k}$	DH_1k	$DH_2\bar{k}$	DH_2k
A	A	B	---	---	---	---	---	---	---
B	A	C	---	A	---	C	---	C	---
C	A	C	A	A	---	C	A	C	A

where $D = d + d_e + d_m$ $F = f + f_e + f_m$ $H_1 = h + h_e + h_m$ $H_2 = h_a + h_c$

TABLE 16. ENGAGEMENT SEQUENCE STATE TRANSITION TABLE
COMMAND AND CONTROL WITH INDIRECT IDENTIFICATION

INPUT STATE	$\bar{d}$	$D\overline{ik}$	$D\bar{i}k$	$DF\bar{k}$	DFk	$DH_1\bar{k}$	DH_1k	$DH_2\bar{k}$	DH_2k
					WEAPONS HOLD				
A	A	B	---	---	---	---	---	---	---
B	A	B	---	A	---	B	---	C	---
C	A	---	---	---	---	C	A	C	A
					WEAPONS TIGHT				
A	A	B	---	---	---	---	---	---	---
B	A	B	---	A	---	C	---	C	---
C	A	---	---	---	---	C	A	C	A
					WEAPONS FREE				
A	A	B	---	---	---	---	---	---	---
B	A	C	---	A	---	C	---	C	---
C	A	C	A	---	---	C	A	C	A

where $D = d + d_e + d_m$ $F = f + f_e + f_m$ $H_1 = h + h_e + h_m$ $H_2 = h_a + h_C$

b. Combination of the first two issues with the airspace management issue illustrates the complexity of the JFAAD problem. Table 10 showed the fire unit's decision process given different weapon control statuses. Table 14 added perception of airspace management compliance to the development of the identification decision presented in Tables 5 and 8. Combining all four tables generates four additional tables that reflect the identification and engagement decisions under each of the means of identification:

° direct visual (Table 17)

° direct electronic (Table 18)

° direct visual and electronic (Table 19)

° and indirect (Table 20)

The unanswered entries in the tables, reflecting areas that must be resolved prior to implementing a closed form resolution of the JFAAD MOE, are broken into many different categories representing different decision conflicts. The categories are summarized in Table 21, which also identifies the broad question that arises in each decision conflict. The conflicts must be studied to define the approach to any JFAAD analysis and to focus research leading to resolution of the MOE.

10. SUMMARY

a. This paper has developed and presented a fire unit engagement sequence for each of the three JFAAD issues. Unresolved questions, requiring thorough doctrinal review, tests and/or surveys of operational personnel, are indicated in Tables 17 through 21. To the extent possible (pending the resolution of those decision tables), the engagement sequence representation for the issues has been combined. The combined representation for the first two issues, broken out by the identification issue systems, is presented in Tables 15 and 16. Although the state transition table was chosen to reflect the combined issues, finite state machines could also be developed from Tables 15 and 16 to provide a different representation of the same results.

b. Further work is required to fill the gaps identified in the fire unit's identification decision process. A thorough investigation of current doctrine coupled with an assessment of SHORAD gunners' normal actions (regardless of doctrine) will provide information pertinent to the air defense community even before the MOE are fully analyzed. Pending the results of that research, the engagement sequence representation can be used as a building block for initial computer model implementation efforts supporting JFAAD. A JFAAD computer model must incorporate those areas addressed in this paper because they reflect the MOP identified in the Test Program Definition.

TABLE 17. DIRECT VISUAL IDENTIFICATION ENGAGEMENT DECISION

INPUT				ENGAGEMENT DECISION			
EARLY WARNING	PERCEIVED ASM COMPLIANCE	VISUAL ID	ID DECISION	WEAPONS HOLD	WEAPONS TIGHT	WEAPONS FREE	COMMAND DIRECTED
U	$\bar{A}$	U	U	$\bar{E}$	$\bar{E}$	E	?
U	$\bar{A}$	F	F	$\bar{E}$	$\bar{E}$	$\bar{E}$	$\bar{E}$
U	$\bar{A}$	H	H	$\bar{E}$	E	E	?
U	$\bar{A}$	H_A	H	E	E	E	?
U	U	U	U	$\bar{E}$	$\bar{E}$	E	?
U	Y	F	F	$\bar{E}$	$\bar{E}$	$\bar{E}$	$\bar{E}$
U	N	H	H	$\bar{E}$	E	E	?
F	$\bar{A}$	F	F	$\bar{E}$	$\bar{E}$	$\bar{E}$	$\bar{E}$
F	Y	F	F	$\bar{E}$	$\bar{E}$	$\bar{E}$	$\bar{E}$
H	$\bar{A}$	H	H	$\bar{E}$	E	E	?
H	$\bar{A}$	H_A	H	$\bar{E}$	E	E	?
H	N	H	H	$\bar{E}$	E	E	?
H	N	H_A	H	$\bar{E}$	E	E	?
H_C	$\bar{A}$	H	H	$\bar{E}$	E	E	E
H_C	$\bar{A}$	H_A	H	$\bar{E}$	E	E	E
H_C	N	H	H	$\bar{E}$	E	E	E
H_C	N	H_A	H	$\bar{E}$	E	E	E

64 Total combinations: (4 EW X 4 ASM X 4 VID = 64)
All those not shown result in Identification Decision conflicts.
Types of Identification Decision conflicts are listed in Table 21.

TABLE 18. DIRECT ELECTRONIC IDENTIFICATION ENGAGEMENT DECISION

INPUT				ENGAGEMENT DECISION			
EARLY WARNING	PERCEIVED ASM COMPLIANCE	ELECTR ID	ID DECISION	WEAPONS HOLD	WEAPONS TIGHT	WEAPONS FREE	COMMAND DIRECTED
U	$\overline{A}$	U	U	$\overline{E}$	$\overline{E}$	E	?
U	$\overline{A}$	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
U	$\overline{A}$	H	H	$\overline{E}$	E	E	?
U	U	U	U	$\overline{E}$	$\overline{E}$	E	?
U	Y	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
U	N	H	H	$\overline{E}$	E	E	?
F	$\overline{A}$	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
F	Y	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
H	$\overline{A}$	H	H	$\overline{E}$	E	E	?
H	N	H	H	$\overline{E}$	E	E	?
H_C	$\overline{A}$	H	H	$\overline{E}$	E	E	E
H_C	N	H	H	$\overline{E}$	E	E	E

48 Total combinations: (4 EW X 4 ASM X 3 VID = 48)
All those not shown result in Identification Decision conflicts.
Types of Identification Decision conflicts are listed in Table 21.

TABLE 19. DIRECT VISUAL AND ELECTRONIC IDENTIFICATION ENGAGEMENT DECISION

INPUT					ENGAGEMENT DECISION			
EARLY WARNING	PERC ASM COMPL	VISUAL ID	ELEC ID	ID DECISION	WEAPONS HOLD	WEAPONS TIGHT	WEAPONS FREE	COMMAND DIRECTED
U	$\overline{A}$	U	U	U	$\overline{E}$	$\overline{E}$	E	?
U	$\overline{A}$	F	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
U	$\overline{A}$	H	H	H	$\overline{E}$	E	E	?
U	$\overline{A}$	H_A	H	H	E	E	E	?
U	U	U	U	U	$\overline{E}$	$\overline{E}$	E	?
U	Y	F	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
U	N	H	H	H	$\overline{E}$	E	E	?
F	$\overline{A}$	F	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
F	Y	F	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
H	$\overline{A}$	H	H	H	$\overline{E}$	E	E	?
H	$\overline{A}$	H_A	H	H	$\overline{E}$	E	E	?
H	N	H	H	H	$\overline{E}$	E	E	?
H	N	H_A	H	H	$\overline{E}$	E	E	?
H_C	$\overline{A}$	H	H	H	$\overline{E}$	E	E	E
H_C	$\overline{A}$	H_A	H	H	$\overline{E}$	E	E	E
H_C	N	H	H	H	$\overline{E}$	E	E	E
H_C	N	H_A	H	H	$\overline{E}$	E	E	E

192 Total combinations: (4 EW X 4 ASM X 4 VID X 3 ELID= 192)
All those not shown result in Identification Decision conflicts.
Types of Identification Decision conflicts are listed in Table 21.

TABLE 20. INDIRECT IDENTIFICATION ENGAGEMENT DECISION

INPUT					ENGAGEMENT DECISION			
EARLY WARNING	PERC ASM COMPL	VISUAL ID	ELEC ID	ID DECISION	WEAPONS HOLD	WEAPONS TIGHT	WEAPONS FREE	COMMAND DIRECTED
U	$\overline{A}$	U	U	U	$\overline{E}$	$\overline{E}$	E	?
U	$\overline{A}$	F	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
U	$\overline{A}$	H	H	H	$\overline{E}$	E	E	?
U	$\overline{A}$	H_A	H	H	E	E	E	?
U	U	U	U	U	$\overline{E}$	$\overline{E}$	E	?
U	Y	F	F	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
U	N	H	H	H	$\overline{E}$	E	E	?
F	$\overline{A}$	---	---	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
F	Y	---	---	F	$\overline{E}$	$\overline{E}$	$\overline{E}$	$\overline{E}$
H	$\overline{A}$	---	---	H	$\overline{E}$	E	E	?
H	N	---	---	H	$\overline{E}$	E	E	?
H_C	$\overline{A}$	---	---	H	$\overline{E}$	E	E	E
H_C	N	---	---	H	$\overline{E}$	E	E	E

60 Total combinations:
(4 ASM X 4 VID X 3 ELID w/No Early Warning + 3 EW X 4 ASM = 60)
All those not shown result in Identification Decision conflicts.
Types of Identification Decision conflicts are listed in Table 21.

TABLE 21. IDENTIFICATION DECISION CONFLICT CATEGORIES

1. DIRECT VISUAL OR ELECTRONIC IDENTIFICATION (Tables 17 and 18)

* Positive direct ID, unknown ASM compliance - does decision wait for resolution of ASM compliance?
* Clear ASM perception, unknown direct ID - does decision wait for resolution of direct ID?
* Positive Early Warning, unknown direct ID - does decision wait for resolution of direct ID?
* ASM perception and direct ID opposite, unknown Early Warning - what is target evaluation scheme?
* ASM perception and direct ID agree, opposite Early Warning - what is target evaluation scheme?
* Early Warning and direct ID opposite, unknown ASM compliance - what is target evaluation scheme?
* Early Warning and direct ID agree, opposite or unknown ASM - what is target evaluation scheme?
* Early Warning and ASM perception agree, unknown direct ID - what is target evaluation scheme?
* Early Warning and ASM perception agree, opposite direct ID - what is target evaluation scheme?
* Early Warning and ASM perception opposite, unknown direct ID - what is target evaluation scheme?

2. DIRECT VISUAL AND ELECTRONIC IDENTIFICATION (Table 19)

appropriate variations of all categories above, plus:

* Visual and electronic direct ID opposite - what is target evaluation scheme?
* One positive direct ID means and one unknown direct ID means - what is target evaluation scheme?

3. INDIRECT IDENTIFICATION (Table 20)

categories in 1 where there is unknown or no Early Warning, plus

categories in 1 where Early Warning and ASM perception conflict

BIBLIOGRAPHY

1. Joint Forward Area Air Defense Test Program Definition, OUSDRE/JFAAD, Fort Bliss, Texas, March 30, 1984.

2. Joint Forward Area Air Defense Model Requirements, Major Otis B. Ferguson, TRASANA, White Sands Missile Range, New Mexico, September 1983, TRASANA-38-83.

3. The Operation Reaction System: A Method for Automated Decision Making for Unit Centered Models, John B. Gilmer Jr., The BDM Corporation, March 22, 1979, BDM/W-79-691-TR.

4. A Model for Command Control at Intermediate Levels in a Unit Centered Combat Simulation, The BDM Corporation, January 29, 1982, BDM/W-81-854-TR.

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